

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-146350

Status Assessment of Toxic Chemicals Cadmium

Monsanto Research Corp, Dayton, OH

Prepared for

Industrial Environmental Research Lab - Cincinnati, OH

Dec 79



United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-79-210f
December 1979

Research and Development

P880-146350

Status Assessment of Toxic Chemicals

Cadmium

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

- 1 Environmental Health Effects Research
- 2 Environmental Protection Technology
- 3 Ecological Research
- 4 Environmental Monitoring
- 5 Socioeconomic Environmental Studies
- 6 Scientific and Technical Assessment Reports (STAR)
- 7 Interagency Energy-Environment Research and Development
- 8 "Special" Reports
- 9 Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

TECHNICAL REPORT DATA
(Please read instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-79-210f		2.		3. RECIPIENT'S ACCESSION NO. PB80-146350	
4. TITLE AND SUBTITLE Status Assessment of Toxic Chemicals: Cadmium				5. REPORT DATE December 1979 issuing date	
				6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) T.R. Blackwood, D.R. Tierney R.D. Willson				8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Monsanto Research Corp. PEDCo Environmental, Inc. 1515 Nichols Road 11499 Chester Road Dayton, Ohio 45407 Cincinnati, Ohio 45246				10. PROGRAM ELEMENT NO. LAB604	
				11. CONTRACT/GWANT NO. 68-03-2550	
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab. - Cinn, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268				13. TYPE OF REPORT AND PERIOD COVERED Task Final 11/77-12/77	
				14. SPONSORING AGENCY CODE EPA/600/12	
15. SUPPLEMENTARY NOTES IERL-Ci project leader for this report is Dr. Charles Frank, 513-684-4481					
16. ABSTRACT The processing, uses, and properties of cadmium are discussed in the report. The effects, major sources, and amounts of cadmium pollutant are listed, along with the control technology currently available. Regulatory actions to deal with the cadmium pollution problem are explained, and areas requiring further study are identified.					
17. KEY WORDS AND DOCUMENT ANALYSIS					
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS		c. COSATI Field/Group	
Cadmium, metals, transition metals, cadmium isotopes		Zinc, smelting, electroplating, nonferrous metal refining, coal combustion		68A 68D 68G	
18. DISTRIBUTION STATEMENT Release to public		19. SECURITY CLASS (This Report) Unclassified		21. NO. OF PAGES	
		20. SECURITY CLASS (This page) Unclassified		22. PRICE	

EPA 600/2-79-210f

ERRATA SHEET

2/11/80

Please change the following:

page iii, paragraph 2, line 3, from "mercury" to "cadmium".

EPA-600/2-79-210f
December 1979

STATUS ASSESSMENT OF TOXIC CHEMICALS:
CADMIUM

by

D. R. Tierney
T. R. Blackwood
Monsanto Research Corporation
Dayton, Ohio 45407

and

R. D. Willson
PEDCo-Environmental, Inc.
Cincinnati, Ohio 45246

Contract No. 68-03-2550

Project Officer

David L. Becker
Industrial Pollution Control Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory - Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related polluttional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains a status assessment of the air emissions, water pollution, health effects, and environmental significance of mercury. This study was conducted to provide a better understanding of the distribution and characteristics of this pollutant. Further information on this subject may be obtained from the Organic Chemicals and Products Branch, Industrial Pollution Control Division.

Status assessment reports are used by IERL-Ci to communicate the readily available information on selected substances to government, industry, and persons having specific needs and interests. These reports are based primarily on data from open literature sources, including government reports. They are indicative rather than exhaustive.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Cadmium is produced mainly as a byproduct of zinc smelting operation. Electroplating processes consume approximately 50% of the 6,045 metric tons of cadmium produced annually. It was estimated that 5,700 metric tons/yr of cadmium are released to the environment from a variety of operations including ore refining, electroplating, fertilizer use, coal combustion, and sludge disposal. About 71% of this is in the form of landfill and 25% is in the form of air emissions. Most of this emission is not as the result of cadmium product. Major sources of cadmium emissions are nonferrous metal refining and coal combustion which respectively contribute 952 metric tons/yr and 235 metric tons/yr of cadmium to the atmosphere. Cadmium contamination in water is primarily from the electroplating industry which releases 160 metric tons/yr. Waste cadmium is deposited on land areas by the landfilling of fly ash from coal combustion and the dumping of slag resulting from steel remelting. Sewage sludge incineration and the application of phosphate fertilizers represent substantial, but less well-defined sources of cadmium pollution. Control technology for cadmium emissions is represented by wet scrubbers, baghouses, and electrostatic precipitators. The efficiency of control exceeds 98% at ore refining facilities.

Under the Federal Water Pollution Control Act, cadmium is a priority pollutant; regulatory standards will be revised by the end of 1979. A criteria document by OSHA concerning stricter regulations on cadmium is anticipated. Air pollution assessments are underway to determine appropriate standards for cadmium under the Clean Air Act. Cadmium is also a suspected carcinogen.

Information should be obtained on the amount of cadmium leached into the environment from landfills, the population exposed to cadmium from industry and cigarettes, the efficiency of wastewater control technologies, and environmental levels of cadmium around major sources (i.e., coal and waste combustion and waste disposal).

This report was submitted in partial fulfillment of Contract 68-03-2550 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period November 1, 1977 to December 31, 1977. The work was completed as of January 20, 1978.

CONTENTS

Foreword	iii
Abstract	iv
Tables	vi
Conversion Factors and Metric Prefixes	vii
Acknowledgement.	viii
1. Introduction.	1
2. Summary	2
3. Source Description.	5
Physical and chemical properties	5
Production	6
Process description.	7
Uses	7
4. Environmental Significance and Health Effects	12
Air emissions.	12
Health effects	17
5. Control Technology.	19
6. Regulatory Action	20
References	21

TABLES

<u>Number</u>		<u>Page</u>
1	Cadmium	4
2	Physical Properties of Cadmium.	5
3	Chemical Properties of Cadmium.	6
4	Zinc Smelter Locations and Byproduct Cadmium Production.	6
5	General Sources of Cadmium Production	7
6	Cadmium Consumption by Industry	10
7	Cadmium Chemicals and Their Producers	11
8	Sources of Cadmium Contamination.	12
9	Emission Factors for Cadmium from Industrial Sources	13
10	Emission Factors for Processes Involving Cadmium.	13
11	Estimated Emission Factors for Consumptive Uses of Cadmium.	14
12	Emission Factors for Cadmium from Fuel Combustion.	14
13	Emission Factors for Cadmium from Waste Incineration.	15
14	Cadmium Emissions	15
15	Cadmium Contamination in Land and Water	16
16	Toxicities of Cadmium Compounds	18

CONVERSION FACTORS AND METRIC PREFIXES^a

CONVERSION FACTORS

<u>To convert from</u>	<u>to</u>	<u>Multiply by</u>
Degree Celsius (°C)	Degree Fahrenheit	$t_F = 1.8 t_C + 32$
Kilogram (kg)	Pound-mass (avoirdupois)	2.205
Kilometer ² (km ²)	Mile ²	3.860×10^{-1}
Meter (m)	Foot	3.2808
Meter (m)	Angstrom	10^{10}
Meter ³ (m ³)	Foot ³	3.531×10^1
Meter ³ (m ³)	Gallon (U.S. liquid)	2.642×10^2
Metric ton	Pound-mass	2.205×10^3
Pascal (Pa)	Pound-force/inch ² (psi)	1.450×10^{-4}
Joule (J)	Calorie (kilogram calorie)	2.386×10^{-4}
Joule (J)	Newton-meter	1.000
Watt	Calorie/second	0.239

METRIC PREFIXES

<u>Prefix</u>	<u>Symbol</u>	<u>Multiplication factor</u>	<u>Example</u>
Kilo	k	10^3	1 kg = 1×10^3 gram
Micro	μ	10^{-6}	1 $\mu\Omega$ = 1×10^{-6} ohm
Milli	m	10^{-3}	1 mm = 1×10^{-3} meter

^a Standard for Metric Practice. ANSI/ASTM Designation: E 380-76^e, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 pp.

ACKNOWLEDGEMENT

This report was assembled for EPA by PEDCo-Environmental Specialists, Inc., Cincinnati, OH, and Monsanto Research Corporation, Dayton, OH. Mr. D. L. Becker served as EPA Project Officer, and Dr. C. E. Frank, EPA Consultant, was principal advisor and reviewer.

SECTION 1

INTRODUCTION

Cadmium is a toxic heavy metal that has been emitted to the environment for many years and is found in soil, water, fish, and food. Cadmium is chemically associated with zinc, copper, and lead-bearing ores and is recovered primarily in conjunction with zinc smelting. Although the toxicity of cadmium at high levels is well known, little is known about long-term exposure at levels found in air, water and fish and other food. This, coupled with the fact that cadmium accumulates in the body and is excreted extremely slowly, has raised concern over the extent of cadmium contamination in the environment.

This report presents an overview of cadmium production processes and end uses, environmental significance, health effects, control technology, and present regulatory action concerning cadmium. Both the amount of cadmium released to air, water, and land by various sources and emission factors for operations involving cadmium processing and use are given.

SECTION 2

SUMMARY

Cadmium is produced as a byproduct of nonferrous metal ore processing; zinc smelter operations accounting for 76% of the available metal. Cadmium production from all sources in 1974 totaled 6,045 metric tons.^a

Industrial uses of cadmium include electroplating, pigment and phosphor production alloys, brazes, electronics, nickel-cadmium batteries, plastic stabilizers, and fungicides. Electroplating operations consume approximately 50% of total cadmium production.

Toxic effects of cadmium in humans have been studied extensively; however, long-term chronic effects of cadmium exposure to humans are relatively unknown. Workers subjected to cadmium for a period greater than 10 yr have shown a marked decrease in respiratory function. The U.S. occupational standard is 0.05 mg/m³ for 8 hr of exposure to cadmium oxide dusts.

Cadmium is listed as a priority pollutant for inclusion as a toxic substance under the Federal Water Pollution Control Act. Best available technology and new source and pretreatment standards for priority pollutants are to be reviewed and revised by the end of 1979.

Table 1 describes sources of cadmium contamination, magnitude of emissions, and possible control. An estimated 5,700 metric tons of cadmium are released to the environment each year. About 25% of this emission goes to the air and 71% is destined as landfill. A very small portion goes to the water environment.

^a 1 metric ton equals 10⁶ grams; conversion factors and metric system prefixes are presented in the prefatory material.

Based upon information contained in this report, the following needs should be considered in future studies:

- The amount of cadmium leached from landfills.
- The population exposed to cadmium from industrial use.
- The extent of exposure due to cadmium in cigarettes.
- The efficiency of wastewater control technology for cadmium and its compounds.
- Environmental levels of cadmium around combustion sources (i.e., coal and waste incineration).

TABLE 1. CADMIUM

Source	Cadmium released to environment, metric tons/yr			Affected population	Control	Regulatory action
	Air	Land	Water			
Ore refining	952			Unknown.	Emissions from smelters controlled by baghouses and wet scrubbers; baghouses, wet scrubbers, and electrostatic precipitators are used in coal combustion; cadmium in water is removed by chemical precipitation and ion exchange.	Cadmium has been named a priority pollutant by EPA under the Federal Water Pollution Control Act.
Pigments and phosphors	10			Ore refining would be smaller than coal combustion or waste disposal.		Cadmium oxide occupational standard reduced to 0.05 mg/m ³ for 8 hr period.
Plastic stabilizers	3					Recommendations by Occupational Safety and Health Administration to further restrict cadmium emissions is anticipated.
Alloys, brazers and electronics	2					Air pollution assessments are underway to determine if emission or performance standards under the Clean Air Act should be initiated.
Remelt steel	100	900				
Fertilizer use	1	87				
Waste incineration	36	237				
Waste landfill		2,168				
Industrial waste disposal			160			
Industrial use of fungicide						
Coal combustion	235	11				
Diesel and fuel oil use	36	744				
Motor vehicle use	11					
Cement plants	32					

SECTION 3

SOURCE DESCRIPTION

PHYSICAL AND CHEMICAL PROPERTIES

Tables 2 and 3 list physical and chemical properties of cadmium, respectively (1).

TABLE 2. PHYSICAL PROPERTIES OF CADMIUM

Parameter	Value			
Atomic number	48			
Atomic weight ($^{12}\text{C} = 12.000$)	112.40			
Melting point, °C	320.9			
Boiling point, °C	765			
Crystal system	hexagonal, close-packed			
Lattice constant, 10^{-10} m	$a = 2.9727; c = 5.606$			
Latent heat of fusion, J/kg	55,308			
Latent heat of vaporization, J/kg	1,200,016			
Coefficient of linear expansion, $\mu\text{m}/(\text{m})(^\circ\text{C})$	29.8			
Capture cross section for thermal neutrons (2,220 m/s), m^2/atom	$2.450 \pm 0.050 \times 10^{-25}$			
Electrical conductivity, percent of International Annealed Copper Standard (IACS)	25			
Electrical resistivity, $\mu\Omega\text{m}$				
20°C	6.83×10^{-2}			
700°C	36.8×10^{-2}			
Specific heat, J/kg (°C)				
20°C	230			
321°C to 700°C	251			
Density, metric tons/ m^3 (°C)	8.65(25)	8.01(330 liq.)	7.93(400)	7.56(700)
Thermal conductivity, $\text{W}/\text{m}\cdot^\circ\text{K}$ (°C)	92(20)	90(100)	44(360)	50(435)
Vapor pressure, kPa (°C)	0.1(394)	1.3(484)	13(611)	53(711)
Viscosity, 10^{-3} Pas (°C)	2.37(340)	2.16(400)	1.84(500)	1.56(600)

(1) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 3. John Wiley and Sons, Inc., New York, New York, 1964. pp. 884-899.

TABLE 3. CHEMICAL PROPERTIES OF CADMIUM (1)

Characteristic	Description
Valence	Divalent.
Reactivity	Reacts with steam to form cadmium oxide and hydrogen; reacts readily with mineral acids, but slowly with organic acids; precipitates from solution with metallic zinc.
Corrosion resistance	Excellent. Presence of sulfur oxides leads to cadmium sulfide formation.
Solubility	Insoluble in alkali hydroxides.

PRODUCTION

Cadmium is produced primarily as a byproduct of nonferrous metal ore processing. Zinc smelter operations produced 76% of the cadmium in the United States in 1972. Table 4 (2) lists zinc smelter locations and cadmium production for each plant (2).

TABLE 4. ZINC SMELTER LOCATIONS AND BYPRODUCT CADMIUM PRODUCTION (1972) (2)

Plant location	Zinc capacity, metric tons/yr	Cadmium production, metric tons/yr
Corpus Christi, TX	50,000	220
Amarillo, TX	74,000	327
Sauget, IL	76,000	335
Blackwell, OK	58,000	255
Bartlesville, OK	45,000	200
Monaca, PA	214,000	941
Palmerton, PA	195,000	858
Bunker Hill, ID	92,000	406
TOTAL	804,000	3,542

- (2) Moll, K., S. Baum, E. Capener, F. Dresch, R. Wright, G. Jones, C. Starry, and D. Starrett. Hazardous Wastes: A Risk-Benefit Framework Applied to Cadmium and Asbestos. EGU-3561, U.S. Environmental Protection Agency, Washington, D.C., September 1975. 272 pp.

For 1974, four general sources of cadmium production are shown in Table 5 (2).

TABLE 5. GENERAL SOURCES OF CADMIUM PRODUCTION (1974) (2)

Source	Cadmium produced, metric tons/yr	Percent
U.S. produced zinc ore refining	1,669	28
Imported ore refining	2,782	46
U.S. produced lead and copper ore refining	186	3
Other sources	1,408	23
TOTAL	6,045	100

PROCESS DESCRIPTION

Cadmium is a byproduct of nonferrous metal ore processing primarily zinc ore. Cadmium is always found with zinc usually in a ratio of 1:1000 to 1:100. The usual form found on land, is cadmium sulfide. No specific cadmium ore is worth mining for its cadmium content alone.

In a typical zinc smelter operation, zinc sulfide concentrates are preroasted, calcined, and then sent to a sintering plant. Cadmium chloride (CdCl_2) and lead chloride (PbCl_2) fumes from the sintering plant are separated from waste gases by a precipitator (1). Cadmium is put into aqueous solution with sulfuric acid. It is then precipitated as a sponge with the addition of zinc dust. The sponge is dried in a filter press and steam dryer. Further refining of the cadmium is accomplished by a reduction furnace. Figure 1 provides a flow diagram of a typical cadmium refining process (1).

Cadmium is also produced from roasted zinc ore by electrolytic refining. A block flow diagram of this process is shown in Figure 2 (1).

USES

Cadmium is used in many processes and products. Because it protects iron from rusting, its main use is in electroplating. Cadmium-plated automobile parts are even more resistant to rust than galvanized (zinc-coated) objects. Cadmium sulfide and cadmium telluride are used in the electronics industry to produce photocells and light emitting diodes. Cadmium sulfide and cadmium sulfo-selenide are used as coloring agents in filled plastics and in some paints. Cadmium stearate is a stabilizer used in plastics to add heat resistance. Cadmium metal is

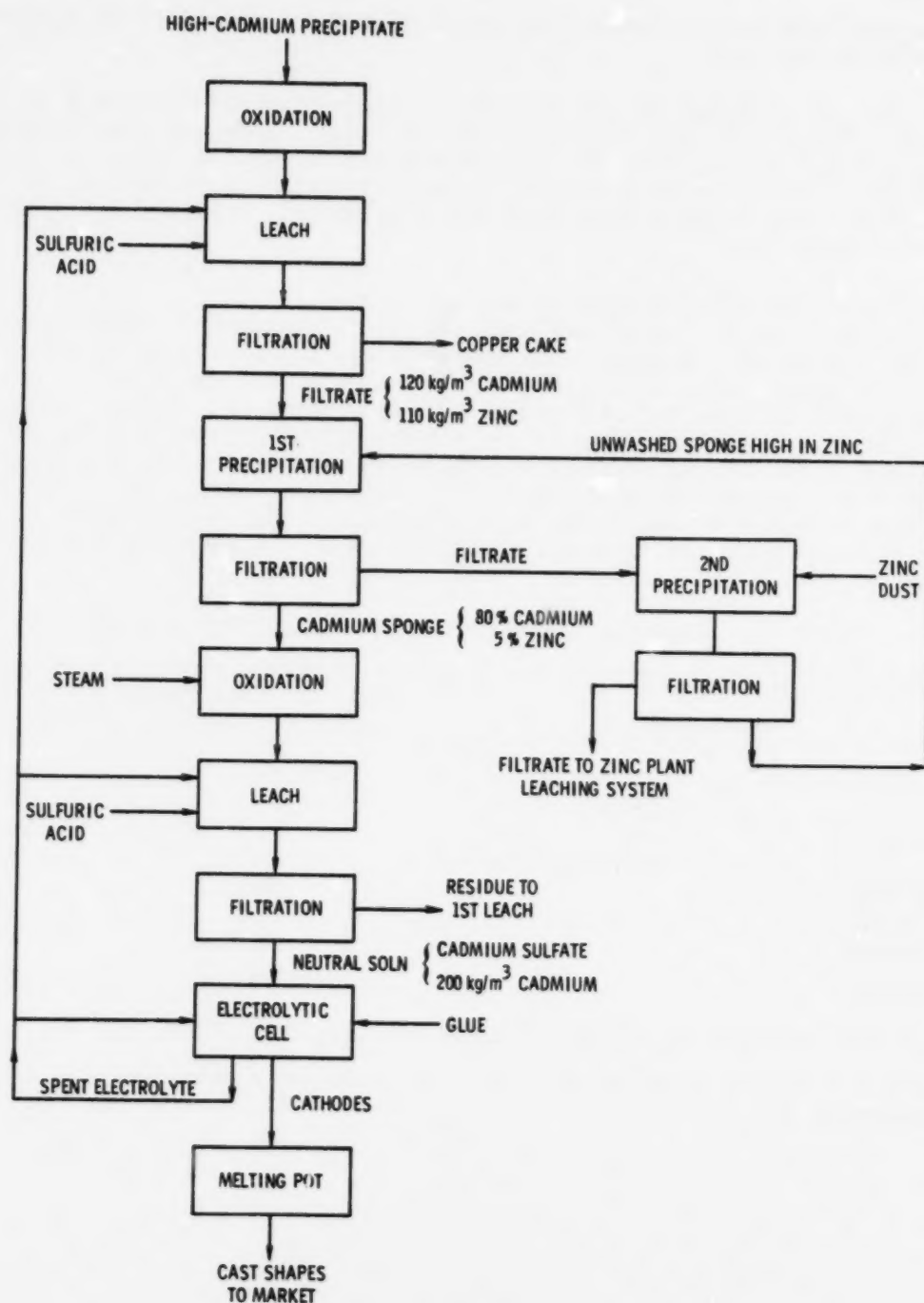


Figure 2. Electrolytic production of cadmium (1).

Kirk-Othmer Encyclopedia of Chemical Technology, Copyright (C) 1964. Reprinted by permission of John Wiley & Sons, Inc.

alloyed with copper which is used in the production of automobile radiators.

The use of cadmium in batteries is projected to increase by at least 15%/yr for the foreseeable future. Although the disposal of nickle-cadmium (Ni-Cd) batteries represents a new and growing source of cadmium release, a number of battery recycling efforts are under way, which may tend to counteract this emission source in the long run.

Although cadmium electroplating encompasses only a small part of the entire metal finishing industry, it represents the greatest use of cadmium. Because its qualities are superior to other plating materials, using substitutes is not likely to become widespread unless it is forced by environmental regulations. The use of cadmium pigments in plastics is expected to grow because even though similiary priced substitutes are available, they also possess significant toxicity problems. The use of barium-cadmium stabilizers for plastic is declining because of the availability of cheaper substitutes. Industrial uses of cadmium are given in Table 6 (2).

TABLE 6. CADMIUM CONSUMPTION BY INDUSTRY (1974) (2)

Industry	Cadmium consumed, metric tons/yr	Percent
Electroplating	2,949	49
Pigments and phosphors	1,270	21
Plastic stabilizers	907	15
Alloys, brazes, and electronics	227	3.8
Ni-Cd batteries	181	3
Fungicides	11	0.2
Other	500	8
TOTAL	6,045	100

Table 7 gives a partial listing of cadmium compounds and their producers (2).

TABLE 7. CADMIUM CHEMICALS AND THEIR PRODUCERS (2)

Chemical	Company	Location
Barium cadmium tetrachloride tetrahydrate	City Chemical Corp.	Jersey City, NJ
Barium dicadmium hexachloride pentahydrate	City Chemical Corp.	Jersey City, NJ
Cadmium acetate	Richardson-Merrell, Inc./J. T. Baker Chemicals	Phillipsburg, NJ
Cadmium acetylacetonate	MacKenzie Chemical Works, Inc.	Central Islip, NY
Cadmium anthranilate	The Shepherd Chemical Co.	Cincinnati, OH
Cadmium bimalate	Mallinckrodt, Inc./Drug and Cosmetic Chemicals	St. Louis, MO
Cadmium bisulfite	City Chemical Corp.	Jersey City, NJ
Cadmium bromide	City Chemical Corp.	Jersey City, NJ
Cadmium carbonate	Richardson-Merrell, Inc./J. T. Baker Chemicals	Phillipsburg, NJ
	Mallinckrodt, Inc./Industrial Chemicals	St. Louis, MO
	McGean Chemical Co., Inc.	Cleveland, OH
	The Shepherd Chemical Co.	Cincinnati, OH
Cadmium chloride	W. A. Cleary Corp.	Somerset, NJ
	Kewanee Industries, Inc./Harshaw Chemical Co.	Cleveland, OH
	Mallinckrodt, Inc./Industrial Chemicals	St. Louis, MO
Cadmium chromate	Richardson-Merrell, Inc./J. T. Baker Chemicals	Phillipsburg, NJ
Cadmium dichromate	City Chemical Corp.	Jersey City, NJ
Cadmium distearate	City Chemical Corp.	Jersey City, NJ
Cadmium 2-ethylhexanoate	CPC International, Inc./S. Z. Penick Unit	Newark, NJ
Cadmium ferrocyanide	The Shepherd Chemical Co.	Cincinnati, OH
Cadmium fluoborate	City Chemical Corp.	Jersey City, NJ
	Allied Chemical Corp./Specialty Chemicals	Marcus Hook, PA
	C. P. Chemicals, Inc.	Sewaren, NJ
	Harstan Chemical Corp.	Brooklyn, NY
Cadmium fluoride	Kewanee Industries, Inc./Harshaw Chemicals	Cleveland, OH
Cadmium formate	City Chemical Corp.	Jersey City, NJ
Cadmium hydroxide	City Chemical Corp.	Jersey City, NJ
Cadmium iodide	The Shepherd Chemical Co.	Cincinnati, OH
Cadmium lactate	Richardson-Merrell, Inc./J. T. Baker Chemicals	Phillipsburg, NJ
Cadmium molybdate	City Chemical Corp.	Jersey City, NJ
Cadmium naphthenate	City Chemical Corp.	Jersey City, NJ
Cadmium neodecanoate	The Shepherd Chemical Co.	Cincinnati, OH
Cadmium nitrate	The Shepherd Chemical Co.	Cincinnati, OH
	Allied Chemical Corp./Specialty Chemicals	Buffalo, NY
	Allied Chemical Corp./Specialty Chemicals	Marcus Hook, PA
	Catalysts and Chemicals, Inc.	Louisville, KY
	W. A. Cleary Corp.	Somerset, NJ
	Kewanee Industries, Inc./Harshaw Chemicals	Cleveland, OH
	McGean Chemical Co., Inc.	Cleveland, OH
	Richardson-Merrell, Inc./J. T. Baker Chemicals	Phillipsburg, NJ
	The Shepherd Chemical Co.	Cincinnati, OH
Cadmium nitrite	City Chemical Corp.	Jersey City, NJ
Cadmium orange	Hercules, Inc./Coatings & Specialty Products	Glenn Falls, NJ
	H. Kohnstamm & Co., Inc./General Color Co.	Newark, NJ
Cadmium oxide	ASARCO, Inc.	Denver, CO
	Richardson-Merrell, Inc./J. T. Baker Chemicals	Phillipsburg, NJ
Cadmium propionate	The Shepherd Chemical Co.	Cincinnati, OH
Cadmium potassium chloride	City Chemical Corp.	Jersey City, NJ
Cadmium potassium cyanide	City Chemical Corp.	Jersey City, NJ
Cadmium reds	Hercules, Inc./Coatings & Specialty Products	Glenn Falls, NY
	H. Kohnstamm & Co., Inc./General Color Co.	Newark, NJ
	SCM Corp./Chemical And Metallurgical Division	Baltimore, MD
	Smith Chemical and Color Co., Inc.	Jamaca, NJ
Cadmium salicylate	City Chemical Corp.	Jersey City, NJ
Cadmium silicofluoride	City Chemical Corp.	Jersey City, NJ
Cadmium stearate	Dart Industries, Inc./Synthetic Products	Cleveland, OH
	Diamond Shamrock Corp./Process Chemicals Div.	Cedartown, GA
	The Norac. Co., Inc./Mathe Division	Lodi, NJ
Cadmium succinate	Witco Chemical Corp./Organics Division	Perth Amboy, NJ
Cadmium sulfate	Mallinckrodt, Inc./Industrial Chemicals	Cleveland, OH
	Kewanee Industries Inc./Harshaw Chemicals	Cleveland, OH
	Richardson-Merrell, Inc./J. T. Baker Chemicals	Phillipsburg, NJ
Cadmium sulfide	ASARCO, Inc.	Denver, CO
	Eagle-Picher Industries, Inc./Electronics	Miami, OK
	Gen. Telephone & Electronics Corp./GTE	
	Sylvania	Towanda, PA
Cadmium tartrate	City Chemical Corp.	Jersey City, NJ
Cadmium telluride	City Chemical Corp.	Jersey City, NJ
	Eagle-Picher Industries Inc./Electronics	Miami, OK
	Division	Quapaw, OK
Cadmium thiocyanate	Thiokol Corp./Ventron, Subsidiary/Alfa Products	Danvers, MA
Cadmium yellows	City Chemical Corp.	Jersey City, NJ
	Hercules, Inc./Coatings & Specialty Products	Glenn Falls, NY
	H. Kohnstamm & Co., Inc./General Color Division	Newark, NJ
	SCM Corp./Chemical and Metallurgical Division	Baltimore, MD
	Smith Chemical and Color Co., Inc.	Jamaca, NY
Ethylenediaminetetraacetic acid, disodium cadmium salt	City Chemical Corp.	Jersey City, NJ

SECTION 4

ENVIRONMENTAL SIGNIFICANCE AND HEALTH EFFECTS

Cadmium is widespread in the environment. Emissions from production and use of the metal are a small part of the total cadmium emissions. This is because the cadmium in many ores is not recovered as a product. One estimate for emissions from cadmium production and consumption was made by EPA in 1974, as shown in Table 8. About 1,800 metric tons of the 6,045 metric tons consumed were immediate sources of environmental contamination. The remaining cadmium may or may not become an environmental contaminant. This will depend on the effectiveness of waste disposal practices, the extent of secondary cadmium recovery and the establishment of future environmental regulations concerning cadmium.

TABLE 8. SOURCES OF CADMIUM CONTAMINATION (2)
(metric tons/yr)

Source	Air	Water	Solid	Total
Extraction, refining, and production	102	7	250	359
Industrial conversion (plating, pigments, batteries, etc.)	15	8	102	125
Consumption and disposal (excluding scrap processing and tire wear)	34	0	460	494
Inadvertant sources (phosphate fertilizers, sludge disposal, etc.)	151	10	720	881
TOTAL	302	25	1,532	1,859

AIR EMISSIONS

The emissions of cadmium from various industrial and commercial operations have been studied extensively. Table 9 shows estimates of cadmium release from various metallurgical refining processes. Table 10 gives emission factors for industrial processes involving cadmium, and Table 11 contains estimated

TABLE 9. EMISSION FACTORS FOR CADMIUM FROM INDUSTRIAL SOURCES

Source	Emission factor, g/kg
Mining of zinc-bearing ore	0.0005 ^a
Zinc smelters	1.0 ^a
Copper smelters	0.4 ^b
Lead smelters	0.1 ^c
Cadmium refining units	13 ^d
Secondary copper	2 ^e
Secondary lead	0.0002 ^f
Steel scrap (galvanized metal)	0.001 ^g
Cement plants:	
Dry process	0.0002 ^h
Wet process	0.0001 ^h

^a g/kg of zinc.^e g/kg of copper scrap.^b g/kg of copper produced.^f g/kg of lead produced.^c g/kg of lead produced.^g g/kg of steel produced.^d g/kg of cadmium produced.^h g/kg of feed.

TABLE 10. EMISSION FACTORS FOR PROCESSES INVOLVING CADMIUM

Source	Emission factor, g/kg of cadmium charged
Pigments	8
Plastic stabilizers	3
Alloys and solders	5
Batteries (Ni-Cd)	1
Miscellaneous (x-ray screens cathode ray tubes, nuclear reactor components, etc.)	1

emission factors for consumption of cadmium-containing end products. Table 12 and 13 give emission factors from fuel combustion and waste incineration, respectively.

TABLE 11. ESTIMATED EMISSION FACTORS FOR
CONSUMPTIVE USES OF CADMIUM

Source	Emission factors
Rubber tire wear, g/km driven	0.003
Fungicides, g/m ³ applied fungicide	20
Superphosphate fertilizers, g/kg applied fertilizer	0.0001
Motor oil consumption, g/10 ³ km driven	0.0006
Cigarettes, µg/20 cigarettes smoked	16

TABLE 12. EMISSION FACTORS FOR CADMIUM FROM FUEL COMBUSTIONS

Source	Cadmium content, ppm	Emission factor
Heating oil (residual assumed)	0.4 to 0.5	4 to 0.05 ^a
Diesel oil	0.07 to 0.1	0.09 to 0.07 ^a
Foreign No. 6 residual fuel oil:		
Virgin Islands	5	5 ^a
Virgin Islands (different oil fields)	<0.4	
Curacao, NA	4	4 ^a
Trinidad	3	3 ^a
Venezuela	<0.4	
Coal, power plant:		
Kansas		0.1 ^b
Coal, power plant:		
Michigan		0.5 ^b

^a g/m³ of oil consumed.

^b g/metric ton of coal burned.

NOTE: Blanks indicate cadmium content is below detection limits.

TABLE 13. EMISSION FACTORS FOR CADMIUM FROM WASTE INCINERATION

Source	Emission factor, g/kg of waste
Sewage sludge incinerators:	
Multiple hearth	0.004
Fluidized bed	0.0002
Municipal incinerator:	
Refuse only	0.0004
Refuse and sludge	0.0003
Overall value for un- controlled solid waste incineration (municipal)	0.0002
Lubricating oil	0.2 ^a

^ag/m³ of oil.

In Table 14, the mass of cadmium air emissions from all types of sources are summarized (2). Compared to Table 10, over nine times as much cadmium is estimated to be emitted from all ore refining than from cadmium-producing ore refining alone.

TABLE 14. CADMIUM EMISSIONS (2)

Source	Mass of emissions, metric tons/yr
Ore refining (zinc, copper, and lead)	952
Pigments and phosphors	10
Plastic stabilizers	3
Alloys, brazes, and electronics	2
Remelt steel	100
Waste incineration	36
Fertilizer use	1
Coal combustion	235
Diesel and fuel, oil use	36
Motor vehicle use	11
Cement plants	32
TOTAL	1,418

Land and Water Contamination

Water pollution due to smelter operations has been studied extensively by EPA; cadmium discharge was found to vary from

0.05 g/m³ to 33 g/m³. Application of effluent limitation guidelines published in 1975 is expected to reduce cadmium pollution of wastewater from all smelter operations to acceptable levels.

Perhaps the most significant source of water-borne cadmium pollution is the estimated 20,000 electroplating shops throughout the country which contribute to the 160 metric tons/yr of cadmium released into the water. Table 15 gives the amounts of water and land contamination due to cadmium (2).

TABLE 15. CADMIUM CONTAMINATION IN LAND AND WATER (2)
(metric tons/yr)

Source	Land	Water
Industrial use of fungicide	11	- ^a
Industrial waste disposal	-	160
Waste incineration	237	-
Waste landfill	2,168	-
Remelt steel	900	-
Fertilizer use	87	-
Coal combustion:		
Bottom ash and slag	245	-
Electrostatic precipitators	499	-
TOTAL	4,147	160

^a Not applicable.

Population Exposed

Cadmium can impact people in a number of ways. Both airborne and waterborne cadmium contribute to an increased concentration of cadmium in soil. In nonindustrialized areas, cadmium in soil is generally less than 1 ppm. The concentration around some localized cadmium point sources reaches 50 ppm or higher. Plants and fish act as bioconcentration media, providing foodstuffs with sometimes alarmingly high cadmium levels. The theoretical models of uptake and excretion of cadmium by humans suggest that the biological half-life is between 15 yr and 25 yr.

Persons may be exposed to high cadmium concentrations in urban areas where industrial consumers of cadmium are usually located such as plating operations, battery manufacture, and pigments production. Cadmium in effluents from these plants, when bioaccumulated in plants and fish, pose a health hazard through a contaminated food chain. Waste incineration and coal combustion are operations which expose a large population to low levels of cadmium compounds. The extent and level of this exposure is unknown. Populations affected around ore refining operations are generally small since the ore is usually processed near the mine

in rural areas. A large portion of the U.S. population may be exposed to cadmium in tobacco which is released as cadmium oxide upon combustion in cigarettes (3).

HEALTH EFFECTS

Cadmium taken orally by humans in the range of 14.5 mg to 326 mg causes nausea and vomiting but not mortality (4). The ingestion of cadmium salts induces salivation, choking, diarrhea, vertigo, and unconsciousness (4).

Studies have shown that workers exposed to low levels of cadmium exhibited deteriorated respiratory functions after only several years of exposure (4).

The normal exposure to cadmium in the environment is not to the metal but rather to cadmium compounds. Selected toxicities for suspected carcinogens containing cadmium compounds are given in Table 16 (5). The 8-hr time-weighted average Threshold Limit Value (TLV®) for cadmium oxide in air is 0.05 mg/m³, while the metal dust has a TLV of 0.2 mg/m³ (6).

-
- (3) Anderson, D. Emission Factors for Trace Substances. EPA-450/2-73-001, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1973. 80 p.
 - (4) Fasset, D. W. The Metals (Excluding Lead). In: Industrial Hygiene and Toxicology, Chapter XXVI, F. A. Patty, ed. Interscience Publishers, New York, New York, 1962. pp. 1013-1016.
 - (5) Suspected Carcinogens. A Subfile of the NIOSH Toxic Substance List. H. E. Christensen and T. T. Luginbyhl, eds. NIOSH 75-188, U.S. Department of Health, Education, and Welfare, Rockville, Maryland, June 1975. 342 pp.
 - (6) TLV's, Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1975. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1975. 97 pp.

TABLE 16. TOXICITIES OF CADMIUM COMPOUNDS (5)

Compound	Lethal inhalation concentration, mg/m ³	Animal	Percent kill
Cadmium oxide	500	Rat	50
	700	Mouse	50
	4,000 ^a	Dog	50
	2,500 ^a	Rabbit	50
Cadmium chloride	320	Dog	0 ^b
	8 ^c	Dog	90

^a10-min exposure.^bLowest single dose observed not to cause death.^c30-min continuous exposure.

SECTION 5

CONTROL TECHNOLOGY

Control technology exists for reducing air and water pollution by cadmium from industrial processes. Other processes which permit large amounts of cadmium to enter the environment are not as easily controlled; e.g., cadmium in sewage sludge and cadmium as a contaminant in superphosphate fertilizers.

The most common methods of removing cadmium from smelter flue gases are baghouses and wet scrubbers. Efficiencies of 99% to 99.8% have been reported. Since cadmium collected can be separated from other constituents and sold, there is no technological barrier in controlling smelter operations; however, disposal still may be a problem. In recycling cadmium-bearing scrap, the iron and steel industry uses baghouses, wet and dry electrostatic precipitators, and wet scrubbers to control fine particulate emissions. Efficiencies of 98% to 99.9% are reported for various processes. The resulting flue dust is usually disposed in landfill operations, where the cadmium may leach into the water table.

Dissolved cadmium in water may be removed by chemical precipitation, ion exchange, solvent extraction, or electrolytic deposition (7). Cadmium in the form of suspended particulate may be removed by settling ponds or thickeners (7). The efficiencies of these control technologies for cadmium are unknown.

(7) Scientific and Technical Assessment Report on Cadmium. EPA-600/6-75-003, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1975. 69 pp.

SECTION 6
REGULATORY ACTION

Under the Federal Water Pollution Control Act, as amended, the EPA has classified cadmium as a priority pollutant for study. Promulgation of new effluent standards for various industries may result. Best available technology and new source and pretreatment standards are to be reviewed and revised by the end of 1979. Water quality criteria will also be developed by mid-1978 for priority pollutants. The U.S. occupational standard for 8 hr of exposure has been reduced to 0.05 mg/m^3 for cadmium oxide dusts (6). A criteria document recommending tightening the Occupational Safety and Health Administration (OSHA) controls is anticipated (8). An air pollution assessment on cadmium has been underway to determine if emission or performance standards under the Clean Air Act should be developed: Richard Johnson, EPA/OAQPS, 919-688-8146, X-501 (8).

(8) Identification of Selected Federal Activities Directed to Chemicals of Near-Term Concern. EPA-560/4-76-007, U.S. Environmental Protection Agency, Washington, D.C., September 1976. 21 pp.

REFERENCES

1. Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 3. John Wiley and Sons, Inc., New York, New York, 1964. pp. 884-899.
2. Moll, K., S. Baum, E. Capener, F. Dresch, R. Wright, G. Jones, C. Starry, and D. Starrett. Hazardous Wastes: A Risk-Benefit Framework Applied to Cadmium and Asbestos. EGU-3561, U.S. Environmental Protection Agency, Washington, D.C., September 1975. 272 pp.
3. Anderson, D. Emission Factors for Trace Substances. EPA-450/2-73-001, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1973. 80 p.
4. Fasset, D. W. The Metals (Excluding Lead). In: Industrial Hygiene and Toxicology, Chapter XXVI, F. A. Patty, ed. Interscience Publishers, New York, New York, 1962. pp. 1013-1016.
5. Suspected Carcinogens. A Subfile of the NIOSH Toxic Substance List. H. E. Christensen and T. T. Luginbyhl, eds. NIOSH 75-188, U.S. Department of Health, Education, and Welfare, Rockville, Maryland, June 1975. 342 pp.
6. TLV's, Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1975. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1975. 97 pp.
7. Scientific and Technical Assessment Report on Cadmium. EPA-600/6-75-003, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1975. 69 pp.
8. Identification of Selected Federal Activities Directed to Chemicals of Near-Term Concern. EPA-560/4-76-007, U.S. Environmental Protection Agency, Washington, D.C., September 1976. 21 pp.